AN UNCERTAINTY PERSPECTIVE WITH PROJECTED CLIMATE CHANGE IN HYDRODYNAMIC MODELLING FOR DELTAIC FLUVIAL FLOODS

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ABSTRACT

Annual fluvial floods have caused significant impacts on livelihood of local residents living in the low-lying Vietnamese Mekong Delta (VMD). In order to eliminate the adverse impacts of future fluvial floods, it is important to project the possible trends of changes after the modification of the boundary conditions and to identify the inherent uncertainties of simulated results. This paper aimed to project the future floods in the VMD and to specify the inherent uncertainties of the future flood extents according to different scenarios of the boundary conditions. The obtained results showed that the area along the coast would be more sensitive to the changes of the sea level while the changes in the nature of the annual flood in the upstream section of the VMD would be subject to the changes of the upstream discharge. Among the two main rivers in the upstream section of the VMD, the simulated stages at Chau Doc were mo0re sensitive to the modification of the sea level in comparison to the simulated stages at Tan Chau. In addition, the stages in middle of the rivers (follow the long-profile direction) in Can Tho and My Thuan would be subject to the changes of both the upstream and downstream conditions.

1. INTRODUCTION

Any numerical model contains certain levels of uncertainty and such the inherent uncertainty has been recognized increasingly (Chen et al., 2011) in order to inform the simulated results (to the relevant stakeholders) with certain levels of warning. Peppenberger et al. (2005) classified uncertainties in flood modelling into five sources: (i) Structure – the assumptions made to simplify reality; (ii) Numerical scheme – the applied set of hydraulic equations (e.g. in ISIS-1D, St. Venant equations were applied); (iii) Topography; (iv) Input/Output – the application of (predefined) rating curves or the output generated by another model; and, (v) Parameters – mainly, hydraulic roughness. In fact, many studies were done to estimate the uncertainty of simulated flood maps by considering a (large) range of the hydraulic roughness (e.g. Manning's n) (Pappenberger et al., 2005; Horritt, 2006; Schumann, 2007) or examining the impacts of boundary condition changes (Pappenberger et al., 2006; Chu et al., 2009; Vastila et al., 2010). In addition, even though it was highlighted that the flood behaviour was climate-driven, the impacts of climate change on the river and hence, flood nature were different according to the unique geo-morphological nature of a region (Petrow and Merz, 2009; Veijalainen et al., 2011). This study was mainly to deal with the fourth type of uncertainty – the relationship between the input and output of a hydrodynamic model. In fact, the study was to quantify the modelling uncertainties (according to the modification of the boundary conditions) and their impacts on the simulated flooding extent and stages. Hence, the main focuses of the study were to: (i) Understand the impacts of upstream and downstream boundary conditions changes on the simulated future spatial flood distribution according to the present (2000) river morphology; (ii) Create the probability flood map according to a projected range of future (physical) conditions; and, (iii) Identify the most sensitive areas subject to the boundary conditions changes.

According to the Mekong River Commission (MRC, 2005), the Vietnamese Mekong Delta (VMD) is generally low-lying with the land surface elevation of less than 5 m above the mean sea level. The hydraulic nature of river network is highly complex with impacts of both the upstream discharge and sea level along the East (semidiurnal tides with the tidal amplitude of about 3.0 to 3.5 m) and West (diurnal tides with the tidal amplitude of about 1. 0 m) Sea. The historical monthly mean discharges was greater than those projected in the future at the beginning of the flood period while it was lower than the projected one during the second half of the period. In other words, the projected fluvial floods would come later in comparison to the past events. The fluvial flood period in the VMD started by June and ended by November, which was about 1 month later than the beginning and ending of the rain season in the Delta. In comparison to the historical mean daily discharge (1985 – 2000), the mean projected mean daily discharge from 2010 to 2050 would start and end later.

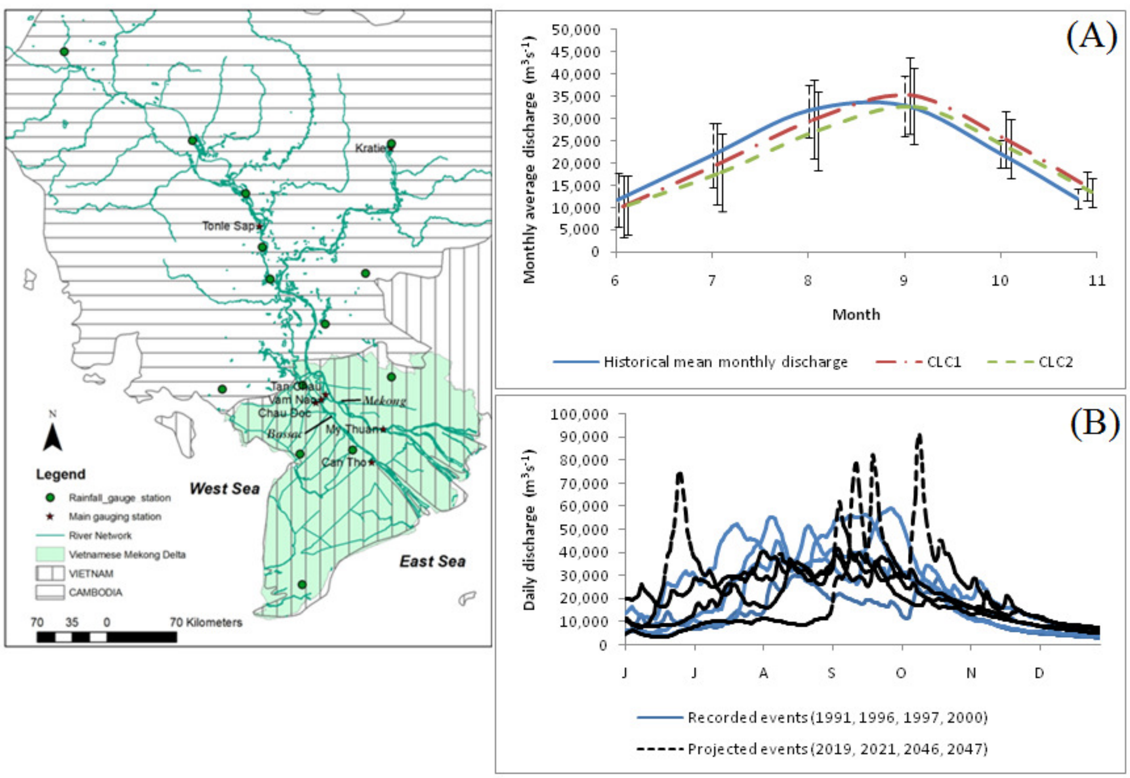

Figure 1: The Mekong Delta and its river network; (A) Historical and projected mean monthly discharges at Kratie; CLC1 and 2: Climate Change Scenario 1 and 2, respectively; the standard deviation bars of the historical and projected mean monthly discharges according to CLC1 and 2 were presented from left to right; and, (B) Annual typical recorded and projected flood hydrographs.

2. METHODS

The ISIS-1D model developed by the MRC (2005) was applied in this study. For the downstream boundary condition, the future sea levels were calculated as the sea level in 2000 adds 20 cm. The upstream boundary conditions were the historical daily measured discharges at Kratie from 1985 to 2000 and the daily projected discharge from 2010 to 2050 with two different scenarios (Scenario 1 – climate change without development at the upstream of the

Mekong Basin and Scenario 2 – climate change with development at the upstream of the Mekong Basin) (Hoanh et al., 2010). Table 1 summaries the scenarios applied in the study.

Table 1: Model runs.

	Upstream boundary (Q_{Kratie})	Downstream boundary (Sea level)
Model run No. 1	[1985 .. 2000]	2050
Model run No. 2	[2010 .. 2050][a]	2050
Model run No. 3	[2010 .. 2050][b]	2050

[(a)] and [(b)]: are corresponding to Scenario 1 and 2, respectively.

3. RESULTS

Figure 2 and Figure 3 present a range of the daily highest simulated stages at Tan Chau, Chau Doc, My Thuan and Can Tho according to the sea level projected in 2050 and the measured (1985 – 2000) and projected (2010 – 2050) flood events. The mean and standard deviation of the simulated stages in Tan Chau were quite similar between the past and projected events; however, in Chau Doc, the projected flood would be lower than that in the past events. In addition, the mean and standard deviation of the simulated stages in My Thuan and Can Tho were similar between different scenarios. With the reference to the historical stage during the flood period in 2000, in the future, the stages at My Thuan and Can Tho would be significantly greater. In addition, in comparison between the recorded and projected hydrograph at Kratie, the similar pattern was also found in Tan Chau and Chau Doc. In general, the future floods in Tan Chau and Chau Doc would come later than the past events.

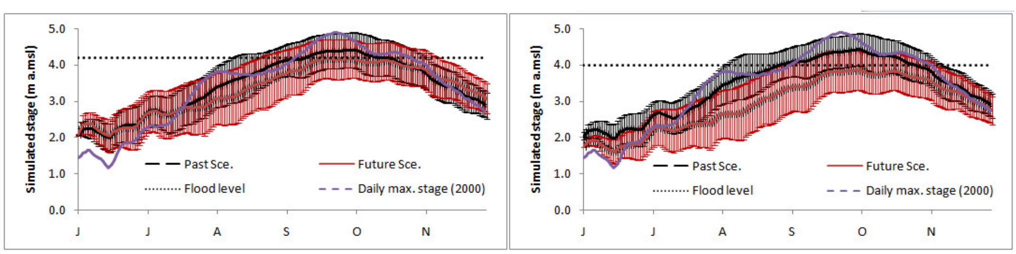

Figure 2: Range of simulated stages at Tan Chau (A) and Chau Doc (B) with the past and future events (with the sea level projected in 2050).

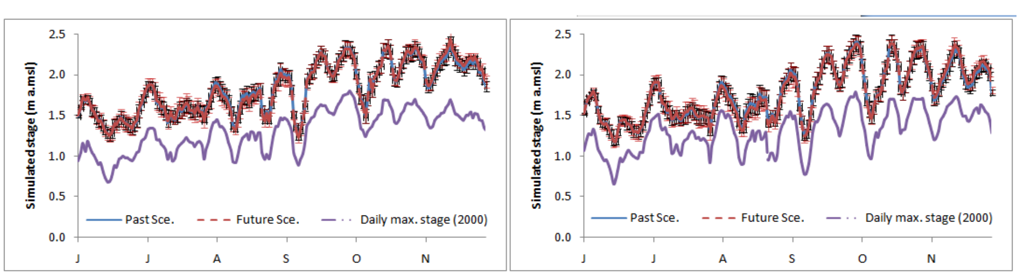

Figure 3: Range of simulated stages at My Thuan (A) and Can Tho (B) with the past and future events (with the sea level projected in 2050).

The average historical flood level at Tan Chau and Chau Doc was 4.2 and 3.5 m a. msl, respectively. At My Thuan and Can Tho, the greatest measured stage in 2000 was 1.80 and 1.79 m a.msl, accordingly. Even though the flood hydrograph in Tan Chau and Chau Doc followed the hydrograph pattern in Kratie rather closely, the simulated stages in Tan Chau and Chau Doc were also influenced by the modification of the sea levels (Figure 4). In addition, the changes of sea level led to significant modification of the simulated stages in My Thuan and Can Tho (Figure 5). The similar patterns of simulated stages in My Thuan and Can Tho with the modification of upstream discharge could be explained as they were strongly influenced by the sea level rather the upstream discharge from Kratie.

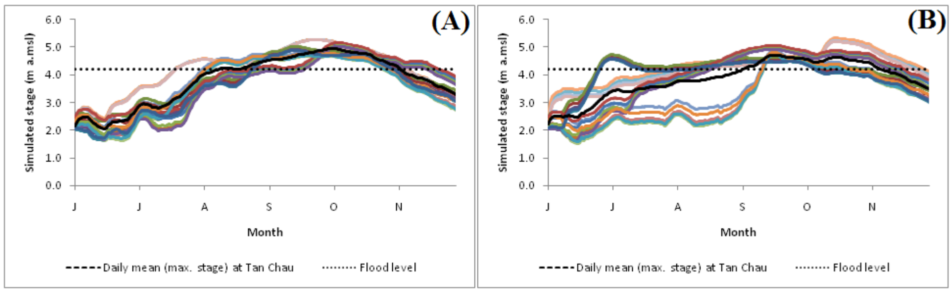

Figure 4: : Range of simulated stages at Tan Chau with the past (A) and future (B) events. Notes: The findings were found similar in Chau Doc.

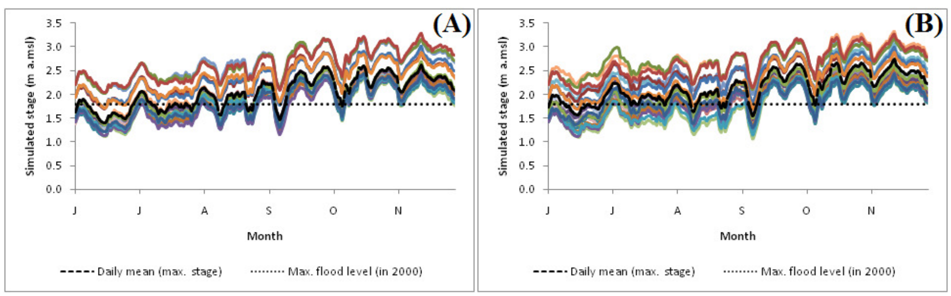

Figure 5: Range of simulated stages at My Thuan with the past (A) and future (B) events. Notes: The findings were found similar in Can Tho.

Due to a larger proportion of the entry discharge entering the VMD routed along the Mekong river reach, with the increase of the discharge during the flood period at Kratie, the absolute discharge along the Mekong would be higher than that along the Bassac. In fact, the ratio between the simulated discharge along the Mekong and Bassac (with the application of the identical bathymetry of the river network and the sea level rise with the similar amplitude for all the downstream boundaries) did not changed significantly overtimes (in average, 77 and 23 %, respectively); therefore, with the extreme flood events, discharge entering the Mekong was much higher leading to greater increase of simulated stages along the Mekong than those along the Bassac. Even though the future flood peaks would be higher than those in the past, the total discharge of flood season in the future would be projected to be lower. Such the projection led to the similar stages projected for the future and measured in the past in Tan Chau while lower stages projected in the future than measured in the past in Chau Doc. With the lower flood in Chau Doc, the benefits from the annual flood (Johnston et al., 2003) might be lost.

Figure 6 presents the highest (A) and most likely (B) simulated stage in the VMD in the flood period (Q_{Kratie}: 2010 – 2050) and probability of the appearance, after model run No. 2. Uncertainty in boundary conditions was considered as one of the main sources of uncertainty in hydrodynamic modelling results. In fact, this paper was to deal with exploring the spatial and temporal distribution of fluvial flood according to the uncertainties of the projected future boundary conditions. It was found that the fluvial flood dynamics in terms of space and time in the VMD was influenced strongly by both the upstream discharge (at Kratie) and sea level in the East and West Sea. In the upstream section of the VMD, the flood extend would be modified according to the changes of the upstream discharge while along the coast, the changes of sea level would result in changes of the flood extend.

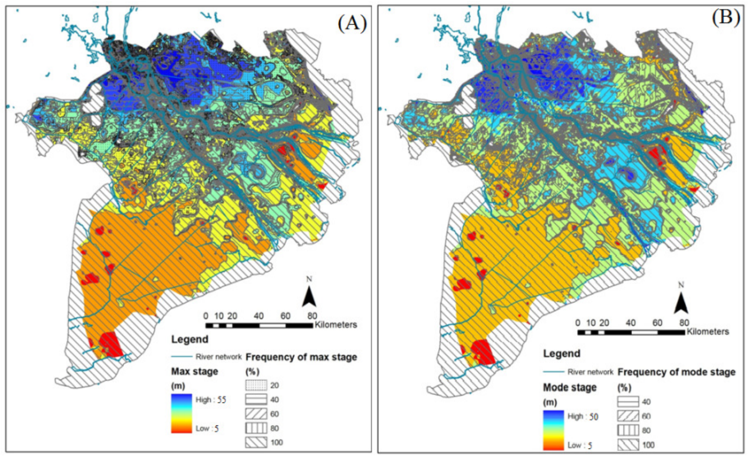

Figure 6: The highest (A) and most likely (B) simulated stage in the VMD in the flood period (Q_{Kratie}: 2010 – 2050) and probability of the appearance; the non-flooded area along the coasts went beyond the scope of the applied model. *Notes*: Results were found similar between model run No. 2 and 3.

With the increase of the downstream boundary condition, water surface slope would be modified and hence the hydraulic roughness (Manning's n) of the channel. However, the study was done with the application of the present condition (in 2000) of the river morphology and stable Manning's n set was applied for both the present and future sea levels, which would not sufficiently reflect the nature of the river network in the future. In fact, due to a dynamics of the alluvial river network in terms of morphology (Schumm, 1971), it was highly suggested to couple the morphological dynamics model into a hydrodynamic model for better projection of the flooding in the future and further study would be required to examine the modification of the hydraulic roughness according to the modification of the downstream boundary condition. In addition, with the limitation of number of simulations, the obtained results were still meaningful in terms of identifying the area which was highly subjected to the changes of the boundary conditions. In this study, changes in bathymetry were not included but only the modifications of upstream and downstream boundary conditions. It would be valuable for the next study to focus on smaller scale and pay more attention to the changes of such fluvial river network which is known to be self-adjusted frequently.

4. CONCLUSIONS AND RECOMENDATIONS

The study was to project the future flood extents in the VMD according to the changes of the physical settings (upstream discharge at Kratie and sea levels in the VMD). Actually, the changes of the upstream and downstream boundary conditions might lead to great impacts of the simulated water level at different spatial and temporal distribution. In addition, the future proportion of the two main inlets of the VMD (i.e. Mekong and Bassac) would be in different from the present conditions. Such the finding might lead to requirements for further research, including: (i) detailed flood dynamic study; and, (ii) coupled morphodynamics – hydrodynamics model at a local scale.

The flood in the downstream section would be more serious if the sea level rose up more than 30 cm. In addition, the flood duration in the downstream section would be also prolonged with the rise of the projected sea level. In addition, due to the relatively flat topography, the changes of precipitation in terms of magnitude but not temporal distribution did not give much influenced on the simulated stages and discharges along the VMD leading to changes of precipitation would result in minor impacts of the hydraulic nature of the river network in the VMD. Finally, the Ca Mau Peninsula would be highly subjected to the modification of the sea level and upstream discharge; the higher the land surface elevation in the coastal area and the Ca Mau Peninsula, the lower the simulated stage and the less sensitive with the changes of the sea level.

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